



Fig. 2. Isopachs of Chicxulub crater ejecta in meters.

fraction of an hour. Deposition of this amount of energy allowed lethal changes in oceanic and atmospheric systems. Release of devolatilized C and sulfur dioxides from the impacted rocks of the Yucatan Platform probably made the Chicxulub impact particularly deadly for its size. Understanding the contributions of different mechanisms to the extinction of species will be more difficult than establishing the location and size of the impact, but having the latter information constrains modeling of the impact's effects.

References: [1] Hildebrand A. R. et al. (1991) *Geology*, 19, 867–871. [2] Swisher C. C. et al. (1992) *Science*, 257, 954–958. [3] Sharpton V. L. et al. (1992) *Nature*, 359, 819–821. [4] Pilkington M. et al. (1993) *JGR*, submitted. [5] Sharpton V. L. et al. (1993) *Science*, 261, 1564–1567. [6] Hildebrand A. R. and Stansberry J. A. (1992) *LPSC XXIII*, 537–538. [7] Sigurdsson H. et al. (1992) *EPSL*, 109, 543–559. [8] Hildebrand A. R. (1992) Ph.D. dissertation, Univ. of Ari

N94-28301

CONSEQUENCES OF IMPACTS OF SMALL ASTEROIDS AND COMETS WITH EARTH. J. G. Hills, Theoretical Division, Los Alamos National Laboratory, Los Alamos NM 87545, USA.

The fragmentation of a small asteroid in the atmosphere greatly increases its cross sections for aerodynamic braking and energy dissipation. At a typical impact velocity of 22 km/s, the atmosphere absorbs more than half the kinetic energy of stony meteoroids with diameters, $D_M < 220$ m and iron meteoroids with $D_M < 80$ m. The corresponding diameter for comets with impact velocity 50 km/s is $D_M < 1600$ m. Most of the atmospheric energy dissipation occurs in a fraction of a scale height, so large meteors appear to "explode" or "flare" at the end of their visible paths. This dissipation of energy in the atmosphere protects the Earth from direct impact damage (e.g., craters), but it produces a blast wave that can do considerable damage. The area of destruction around the impact point in which the over-pressure in the blast wave exceeds $4 \text{ lb/in}^2 = 2.8 \times 10^5 \text{ dynes/cm}^2$, which is enough to knock over trees and destroy buildings, increases rapidly from zero for chondritic meteoroids less than 56 m

in diameter (15 megatons) to about 2000 km^2 for those 80 m in diameter (48 megatons). (The probable diameter of the Tunguska impactor of 1908 is about 80 m.)

Crater formation and earthquakes are not significant in land impacts by stony asteroids less than about 200 m in diameter because of the air protection. A tsunami is probably the most devastating type of damage for asteroids 200 m to 1 km in diameter. An impact by an asteroid this size anywhere in the Atlantic would devastate coastal areas on both sides of the ocean. An asteroid a few kilometers across would produce a tsunami that would reach the foothills of the Appalachian Mountains in the upper half of the East Coast of the United States. Most of Florida is protected from a tsunami by the gradual slope of the ocean off its coast, which causes most of the tsunami energy to be reflected back into the Atlantic. The atmosphere plume produced by asteroids with diameters exceeding about 120 m cannot be contained by the atmosphere, so this bubble of high-temperature gas forms a new layer on top of the atmosphere. The dust entrapped in this hot gas is likely to have optical depths exceeding $\tau = 10$ for asteroids with diameters exceeding about 0.5–1 km. The optical flux from asteroids 60 m or more in diameter is enough to ignite pine forests. However, the blast wave from an impacting asteroid goes beyond the radius in which the fire starts.

The blast wave tends to blow out the fire, so it is likely that the impact will char the forest (as at Tunguska), but the impact will not produce a sustained fire. Because comets dissipate their energy much higher in the atmosphere than asteroids, they illuminate a much larger region and their blast wave is weaker, so they are much more effective in producing large fires. This suggests that the KT impactor was a comet rather than an asteroid.

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ESTIMATION OF THE MEASURES OF THE CHICXULUB CRATERING EVENT. K. A. Holsapple, Mail Stop FS-10, University of Washington, Seattle WA 98195, USA.

Introduction: The impact of a large asteroid or comet into the Earth sets in motion a very complex event with severe consequences. The energy from the impact of a 10-km body at 20 km/s velocity is $10,000\times$ greater than the sum of the energy from the simultaneous detonation of all nuclear devices in the world [1]. That energy is deposited into what is, compared to the range of the effects, a single spot in the lithosphere. The consequences of such an impact are well outside any known experience, and require extreme extrapolations of limited data to estimate.

The most important link to the estimation of the other aspects of the crater formation is the remaining final crater. Here we review the existing methods of estimating the relations between the conditions of the impact: the impactor composition, size, and velocity; and the resulting effects: crater size, ejecta deposition, dynamic flow fields, melt volumes, etc.

Database: The quantification of cratering phenomena is based on results of four types. Those types and some comments on their importance and limitations follow.

Experiments in the laboratory. Since the 1960s experimenters have formed centimeter-sized craters in a variety of materials at velocities up to about 6 km/s. In the 1980s, experiments were also performed at high gravity on a centrifuge [2]. Primarily from these data, two distinct physical regimes for cratering have been identified, depending on the relative magnitudes of material strength c com-